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No. 858

THE FOCKE HELICOPTER

By H. Focke

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The successful record flights of the Focke helicopter of the past year have surprised the world and have brought nearer the first practical solution of a problem that has long occupied the attention of the aeronautical engineering world. It may be expected that with further perfecting of the new type of aircraft new fields of application of aviation hitherto closed will be opened up. Professor Focke has, at our request, made available the following contribution in which he explains in detail the main ideas by which he was guided in his work and describes the methods which finally led to his successful achievement. (Editors)

There is no doubt that the attainment of zero velocity in the air as well as vertical take-off and landing has been a goal striven for in aeronautics that up to the present has not met with any marked success. Performance characteristics such as the above are quite impossible of attainment by the conventional airplane since the latter's ability to sustain itself and its controllability depend on the relative wind in forward flight.

When, thirty years ago, the conventional airplane, as a result of the fundmental simplicity of its design, gained ascendancy over the other types of heavier-than-air craft it seemed that its line of development would be the only one followed. Great progress with this type of airplane has, as a matter of fact, been made, although the progress has been only gradual and no fundamental changes have been made from the original design.

However, with the first visible successes of 1907 to 1909 a circumstance arose which, when viewed from a broader point of view, may be considered as unfortunate as it has served to create hindrances that should have been unnecessary. The unfortunate circumstance referred to is the fact

*"Der Focke-Hubschrauber." Luftwissen, vol. 5, no. 2, February 1938, pp. 33-39.

that the conventional type airplane, which was the type that had met with some degree of success, was henceforth practically the only one that came to be produced and all other parallel attempts that had up to that time been made on other types tended to be forgotten. For two or three decades the fact was overlooked that a single practical solution did not necessarily constitute a proof of the impracticability of other possible solutions.

The tenacity with which the methods that made possible the first successful flights were adhered to is something that can be readily understood and, similarly, the overlooking of the fundamental deficiencies of this first solution.

We are well aware of the limitations to which our present-day airplane is subject. Of these we take account, and direct our efforts accordingly. We keep on making improvements within the limits of its possibilities. This is, of course, proper. We need not, for this reason however, forget one thing as regards the future, namely, that new and wider fields of application which today we find closed to us can be conquered only by going back to the roots of our technical knowledge and seeking new paths.

The problem of designing an aircraft that is to be independent of its forward velocity having once been stated, a requirement immediately enters that can in no way be set aside, namely, that of imparting to the lift members a motion relative to the air. Furthermore, it will be necessary in practice to satisfy this requirement with the greatest possible structural simplicity. Although flapping and bucket-wheel types of aircraft hold out certain technical "lures," calm consideration shows that one of our simplest and also theoretically best known mechanical elements, namely, the air propeller, is still the most suitable.

The idea of a power-driven propeller with vertical axis as a flying device is very old. Leonardo da Vinci had already sketched a first helicopter. Two impulses of quite different origin have in recent times been responsible for the strong interest taken in the helicopter. The first arose from sheer necessity, the take-off and landing in a restricted space as, for example, on ships without airplane catapults, application as liaison airplanes, mountain and colonial airplanes, geographical researches, special tasks of surveying, radio, etc.; all these required a machine with not only moderate, but with even very small take-off and landing distance, possibility of hovering in the air, and arbitrary climb and gliding angles up to the vertical. Likewise, any extended private air communication of the future with the conventional-type airplane will always come up against the difficulty, unavoidable no matter what we try to do about it, of the requirement of a large space for landing and take-off. With a well-developed helicopter, however, roof and garden landings are no longer a Utopia.

The second impulse referred to above came entirely from the technical side. De la Cierva, with his autogiro, has shown practically that a large rotating propeller is a reliable lifting device, as had also been emphasized by him so many times. To be sure, his machine is not a helicopter and cannot therefore rise and land vertically or hover in the air since the rotor is not driven by the engine but "autorotates" freely under the action of the relative wind which is still required. The forward motion is obtained in the usual manner by engine and propulsive propeller.

Unquestionably the autogiro represents a noteworthy intermediate solution between the conventional airplane and the helicopter. By its very existence it has on the theoretical side provided us with insights into which without it we should have had a long time to wait. The government authorities in England who were to test Cierva's autogiro have provided such experts in aerodynamics as Glauert and Lock with the stimulus for rendering a clear explanation of the peculiar process of autorotation, i.e., of the fact that the large propeller at small angles of attack turns freely under the action of the relative wind.

An extension of the Glauert-Lock computation method to the forward flight of a helicopter is theoretically possible down to very small velocities and has served as the theoretical basis for the construction of my helicopter.

As regards the progress that had been made at the beginning of my work on helicopters in 1932, the following performances of the Pescara (France), d'Ascanio (Italy), and Oehmichen (France) were officially or at least semi-officially confirmed:

range	about 1 km
duration	about 10 min.
altitude	about 18 m

No continuous flights with a helicopter, even only on the experimental level, have been recorded, however.

With this state of affairs, and with the general state of flight technique and flight science, the problem cannot be solved by merely adding to the many previous designs still another which perhaps would fly several meters higher and farther without ever becoming adapted to practical flight. The only solution was to create an aircraft, although at first only an experimental aircraft, that was truly worthy of the name. The attainment of this object, however, must be striven for with all the technical means at our command. Inventive ideas are good and necessary but a calm consideration of all points of view of importance to the problem and the working out of all technical foundations is the better method.

The requirements which practice will impose on the completed aircraft and which are the determining factors for the points of view mentioned above follow in the order of their importance:

1. Possibility of a forced landing in case of engine failure.- This basic requirement, by far the most important, has not been practically satisfied by any helicopter although the theoretical possibility of allowing the propeller to go into autorotation has long ago been pointed out even before Cierva. For this purpose it is necessary that the blade setting of the propeller be reduced as compared with the operation of the same propeller as helicopter, since by this means alone is autorotation assured. This means further mechanical complexity which, however, cannot be dispensed with since an aircraft without the ability, after failure of the engine or force transmission gear, of landing smoothly is unthinkable as a practical machine. The next important requirement is that of:

2. Controllability and stability.- The aircraft must, at least with normal skill of pilot, be controllable in all flight conditions, hence also when it is hovering in

the air. It is still better to have static stability about all axes and, as far as possible, also dynamic stability. This is where the sore spot lay in all the previous helicopter tests. In most cases it was reported that only through simultaneous, exact, lightning-fast control motions was it possible to keep these helicopters for some minutes in the proper attitude. In the case of other designs which, for other reasons were later dropped, it was claimed that they had shown themselves to be stable without any explanation for such stability being offerred. The prophecies of Kármán probably had much to do with the pessimistic statement that practical, continuously flying helicopters, were impossible.

3. General safety in operation.- In this respect, too, lay a great weakness of the helicopter. There could hardly be any talk of safe operation where the duration of flight was still reckoned in minutes. To be sure, the fixed structural parts are subject to hardly any conditions other than those for the main body structure in the case of the conventional airplane. The driving parts, however, must be made at least as reliable as the engine, whose reliability of operation will be smaller and presumably will remain smaller than that of fixed airplane structure. It is understood of course that we are considering here the reliability of operation in general which determines the continuous practical usefulness of the aircraft. The ability to make a forced landing discussed under 1, is an essential preliminary condition that must be satisfied, together with the reliability of operation of the structure. Directly connected with the practical usefulness is the requirement of:

4. Simplicity of the piloting maneuvers.- The technical side of a new problem is always only a part, perhaps the smaller part of the whole problem. The other part concerns the one who is to drive the new machine. It is therefore one of the most urgent requirements to render this task of piloting as easy as possible for him. It is all the more necessary to provide him with methods of control and control members with which he is acquainted or which in any case require only a few more manual controls. Furthermore, we cannot dispense with the requirement of:

5. Acceptable performance.- It is obvious that we cannot expect, particularly at the beginning, that the

maximum performance of the conventional-type airplane will be attained. On the other hand, a price must be paid for the exceptional performance of rotating-wing aircraft in the region of low velocities. Still the value of a helicopter will be seriously restricted if, for example, it were only able to hover in one place in the air. We shall therefore have to require that its performance be at least comparable with that of the airplane. Finally, a not unimportant requirement is that of:

6. Reasonable servicing.- It is naturally necessary for the personnel working with a new type of aircraft to get accustomed to it. Nevertheless, we must emphasize that the body should require about the same type of servicing as that of the conventional airplane and the engine about the same as that of an ordinary aviation engine. There will then arise no greater difficulties after a certain initial period.

The above enumeration of only the main requirements shows that for the problem of the ideal rotating-wing aircraft there exists no surprise solution by any invention, patent, or Columbus egg, but that only one way is open, that of making a thorough study with equal care of the many diversified questions and taking them all into consideration in the design. Many of the questions such as the extensive stability investigations are of an entirely theoretical character. Others, for example, the problems of simple manipulations and control, are primarily of a practical nature. Between these are to be found the difficult problems in connection with the construction of the aircraft parts.

The production of lift of a propeller.- The generation of a propeller thrust which is here equivalent to lift offers nothing particularly new. The computation has been performed so often and so thoroughly that little remains to be added. The three-blade propeller of tapered plan form was also subjected to extensive wind tunnel investigations both as a helicopter and as an autogiro propeller. Figure 1 shows a model of this three-blade propeller driven by a three-horsepower electric motor. The outfit rests on the wind-tunnel scales, which measure all air forces and moments.

The measurements require great care since there are many sources of disturbance, the details of which cannot be individually discussed here. One essential circumstance will be mentioned, however, since it also has a direct bearing on practical helicopter flight, and that is ground effect. On approaching a sufficiently large horizontal plane there is a considerable increase in the thrust and to a smaller extent also in the torque of a propeller, as soon as the distance becomes comparable with the propeller diameter. In practice this effect is very marked. With a given throttle setting the helicopter lifts off the ground, but with no more power supplied to the engine, does not rise above a few meters. A helicopter without sufficiently great excess power will never rise above this "floating level." On the other hand, this phenomenon gives rise to a welcome cushioning effect in landing. Up to the present only a few tests on ground effect have been available, the best ones still being those of Flachsbart (1928) which were well confirmed by our own measurements. The upper curve of figure 2 gives the increase in thrust, the lower one that in the torque with decreasing distance from the ground expressed in propeller diameters. The three points marked with crosses are those corresponding to our own measurements.

Control and stability.- No control is thinkable without a previous existence of complete balance of the moments. This is where the well-known difficulty, which to a large extent has stamped the whole character of the helicopter problem, lies. The large, slowly rotating propeller exerts an unbalanced moment of the order of hundreds to thousands of kg-meters on the aircraft. The manner in which this moment is balanced determines the entire structural character of the helicopter. Many designs have been proposed as shown in figure 3. Two oppositely rotating propellers placed one above the other (a) Bréguet, d'Ascanio, Pescara, Asboth), (b) two propellers one behind the other (Cornu) or even four, one at each of the corners of a square (de Bothezat, Oehmichen), (c) two oppositely rotating propellers side by side (Berliner, Focke), (d) apparently paradoxical, two propellers rotating in the same direction, but with axes so inclined that the lateral components of the total moment are eliminated (Florine, Belgian Government), (e) a single large screw on whose blades are located small propellers (Isacco, Curtiss-Bleeker), (f) the blades carry out flapping motions so that no unbalanced moment arises, further, (g) a single helicopter propeller and on long outriggers of the fuselage one or more propellers whose thrust opposes the helicopter moment, (Baumhauer, Holland), (h) a propeller mounted behind the helicopter screw and in whose slipstream are placed deflecting vanes (Hirtenberger Patronenfabrik, Austria), (i) such vanes have even been tried in the helicopter slipstream itself (Hafner and Nagler, Austria). Finally, there has been proposed a method of drive by reaction nozzle (k) (Dornier patents, Papin and Rouilly, France, with counterbalanced single-blade propeller and air under pressure).

Of all these proposed designs we may immediately eliminate those which require a considerable additional power expenditure or involve a loss in performance. These are (e) for which the efficiency of the small propellers enters into the propulsive output of the helicopter so that about 30 percent is lost, (g) and (h), where to produce the reaction force continuous power must be expended which, with a feasible design, may be estimated as from 20 to 30 percent. Also, in order to realize any practical design we must exclude those designs the bases of which are not yet sufficiently clear. These are (f) and (i), reaction and flapping drives. Both may possibly be called on later to play a part. Type (d) offers no advantages as compared to (b) and (c), the inventor having wished to maintain the gyroscopic effects which are lost with the oppositely rotating propellers. If we further exclude the use of more than two propellers for the present on account of the increasing mechanical difficulties there remain three possibilities, namely, two oppositely rotating propellers, one above the other, one behind the other, or side by side. Up to the present the first of these has generally been built. The most successful helicopter up to the past year, especially that of Bréguet-Dorand in France, had this arrangement. Considering the matter more closely, however, and the fact that so many constructions were doomed to failure, this solution, too, cannot be considered as final. In the first place, the designers keep on reporting of the almost insuperable difficulties due to the vibrations which are excited by the arrangement of blades rotating one above the other. Furthermore, the efficiency of the propellers with this arrangement is generally smaller than that of separately running propellers. The slipstream acts on the entire surface of the aircraft, on the fuselage, control members, etc., thus resulting in a lowering of the effective thrust. An approximate calculation shows that the advantage of saving in weight as compared with the side-by-side arrangement is thereby to a large extent offset. In the case of forced landing with propeller acting as windmill a smaller disk area is made available.

Also in the case where the propellers are arranged one behind the other there is, at least in forward flight, a very considerable influence exerted on the rear propeller by the forward one. The fact must be considered that behind a helicopter propeller downwash directions are encountered to which we are not accustomed in the conventional airplane and these have a strong effect on the pitching moments.

The only arrangement which permits no unfavorable interactions of the two propellers is the side-by-side arrangement on the fuselage. Induced vibrations of the blades will in this case not occur. In the case of forced landing the full disk areas of both propellers are available, their mutual induction having the effect of increasing the aspect ratio. The efficiency is always as high as for the case of the single propeller. There is practically no interference and only the essential parts lie in the slipstream. The space requirement is also not very different since what is saved in span in the case of the vertical arrangement must in part be made up in length and above all in height.

We now come finally to the consideration of the stability and controllability. Many autogiros are controlled and stabilized by tail surfaces of the type used on conventional airplanes. In the case of the helicopter, when it is hovering in the air, this is no longer possible. The idea naturally suggests itself of using fixed vanes and movable surfaces in the slipstream of the helicopter or that of a normal propeller and both of these methods have, in fact, been tried by us as well as others but with little success. More suitable to the fundamental character of the helicopter is the control and stabilizing by utilizing the propeller blades themselves, a method that has been applied on my machine.

Special careful attention has been given to the stabilizing and control processes at the instant of conversion from helicopter to autogiro (or windmill) flight. Exact instructions could therefore be given to the pilot, particularly on the possible manual operations and trimming of the stabilizer surfaces. In actual flight control was effected as was predicted by the computations and a 3-point landing was obtained the very first time from an altitude of 400 meters. About two seconds after conversion from helicopter to windmill the machine was executing normal gliding flight. It may be said that this performance, which Pilot Rohlfs first accomplished on May 10, 1937, and has since then often repeated, marked the beginning of practical helicopter flight. The ghost of engine failure had lost its terror.

I should not omit to mention the fact that the computational and experimental work involved before these results were attained was very great. Stability computations, in particular, become formidable in extent. Since new territory is everywhere encountered, conscientiousness requires that abbreviated methods and the neglect of certain factors be avoided. If such methods must be used, for example, because the limits of the mathematical possibilities have been attained, then they must be justified by a large number of special, even tedious, tests. The success attained, however, has justified the efforts expended. The first free flight of my machine lasted 28 seconds, the fourth 16 minutes. Even if a large part of the credit may be ascribed to the skill of Pilot Rohlfs, the results achieved would have been unthinkable without a thorough sifting of the technical material.

Considering now the performance, I should like to differentiate between what is already directly attainable today, or shown to be possible, and what we are to expect in a more distant future from the rotating-wing aircraft.

a) Autogiros

Schrenk has made an interesting comparison between the characteristics of airplanes and autogiros (fig. 4). The actual difference occurring is partly due, however, to the impaired relations with respect to the harmful drag which by better streamlining of the propeller hub, etc., may be reduced in the future. It may therefore be estimated that an autogiro will remain inferior to the conventional airplane as regards speed by about 10 percent, but on the other hand, has about half the minimum velocity.

With regard to the climb performance the comparison appears still more disadvantageous. Since we are now in the upper portions of the polar curves the drags become very high. The smallest required power for level flight is considerably higher than in the case of the conventional airplane and occurs also at smaller velocities, a circumstance which is undesirable on account of the propeller efficiency. It is this fact which confirms the view we had expressed at the beginning, namely, that the autogiro is destined to play only the part of a transition aircraft from the conventional airplane to the helicopter. The autogiro fails to solve half the problem since, while it makes possible landing in a small space, it does not permit a velocity zero while the take-off and all other performances connected with the climb characteristics are less favorable. As regards weight, there is no essential disadvantage. On the contrary, particularly in large designs, the reduction in weight caused by the use of lifting surfaces free from forces due to pressure and extended by the centrifugal forces should more than offset the heavy propeller hub and starting gear. This is a very valuable property of all rotating-wing aircraft and hence also of

b) Helicopters

which we shall now consider. In regard to the question of weight we must still make the greatest sacrifice, probably the only one in the future. The gears must transmit to the propellers with sufficient reliability the full maximum power of the engines, a circumstance which in the case of small aircraft puts the helicopter at a disadvantage as compared with the conventional airplane. Bréguet has computed a helicopter of 16 tons gross weight and claims to have found a saving in weight as compared with the corresponding airplane. Although this appears too optimistic, it may be stated roughly that with increasing size of aircraft the proportion of the weight taken up by the drive gear will be reduced sharply as compared with the weights very small due to absence of pressure forces of the lifting parts.

As regards the maximum velocity the question arises at the very beginning whether it is advantageous to have a given rotating-wing aircraft operate as an autogiro or as a helicopter, that is, without propulsive propeller. For it is conceivable that our initial requirements would be met if the helicopter in high-speed flight would operate as an autogiro or in some intermediate state. This important question we have investigated by a detailed computation supported by tests and have obtained the interesting result that the same aircraft operating as a pure helicopter is considerably faster even after 10 percent had to be deducted for engine cooling. Practical experience with my helicopter has well confirmed this result.

The high-climb performance of the helicopter is also very marked. Figure 5 gives a comparison of the measured rates of climb at the ground and the weights of the Fw 44 "Stieglitz," the Cierva C 30, and the helicopter flown both as helicopter and as autogiro with the same Sh 14a engine. It should be observed that the weights were not equal; the helicopter is heaviest, but nevertheless has the greatest climb performance. The autogiros fall quite behind.

I should like to point out at this place that my high opinion of the helicopter is not necessarily based entirely on the proof of its equal or higher climb and speed performance as compared with the airplane. The helicopter is justified by its peculiar properties which determine its special purposes. It is all the more advantageous that it is at least not very inferior to the airplane.

So far, we have considered the extensive knowledge that was necessary for the development of a helicopter. Again it must be emphasized to what a large extent science has formed the basis for building up the new knowledge. The second and still more difficult part of our task consisted in putting this knowledge to practical application in design, construction, and testing.

The first step was the construction of a free flying model (fig. 6). It was driven by a 0.7-hp. two-stroke-cycle engine and with 50 gallons of gasoline had a gross weight of 4.9 kg. It will be understood that it was more often apart than together but it nevertheless furnished us with many valuable experiences. In November 1934 it attained an altitude of 18 m, which happened to be the world record at the time for large, manned helicopters.

We further subjected the engine, together with its coupling and the blade control, to a test somewhat as is done in the case of a new engine. The Brandenburg engine works, which under the personal direction of Mr. Wolff took upon itself the difficult task of the construction of this gear and the modification of the Sh 14a engine and achieved such marked success, at first constructed only one side of the driving gear. It was mounted with a single helicopter blade and the supporting structure on a mock-up fuselage. The helicopter was electrically driven, using a Leonhard system so that the propeller power could be measured. The thrust was measured by the suspension of ballast, the fuselage being made rotatable about its longitudinal axis, and the ground effect being taken into account. A 50-hour continuous run was made and the controls tested.

Figure 7 shows the bevel gear drive with the friction coupling and the safety devices which, in the case of injury to the engine or gear or lowering of the rotational speed below a certain minimum, automatically convert the helicopter propeller to a windmill. Figure 8 shows one of the propeller hubs with the control parts for the blade motion.

The construction of the body and of the propeller was made to follow the lines of a normal airplane. For cooling the engine in hovering flight, a blower propeller was developed and by cylinder-temperature measurements was tested in cooperation with the Brandenburg motor works. (See fig. 9.)

The completed model was at first "flown" many times while anchored to the ground (fig. 10). These "captive flights" are an excellent means of testing since all flight conditions are completely simulated while the helicopter is no more than 0.5 to 1 m above the ground. No stage of testing was attempted without previous investigation of the preliminary conditions by computation or special test. On June 25 and 26, 1937, this model was able to bring to Germany all the helicopter world records by outstripping the existing performances 15-fold (fig. 11). The altitude attained of 2,439 meters (9,000 ft.), which by no means was the absolute ceiling has given rise to the rather unconcealed charge of deception against me on the part of Mr. Asboth in a foreign technical journal. Asboth doubts, in particular, that the aircraft operated as a pure helicopter in attaining this altitude and thinks it probable that the aircraft at that altitude was flown as an autogiro like that of de la Cierva. He believes he is able to show by computation that this altitude could not have been attained as a helicopter, giving figures and weights that are far from actuality. I should like to state at once - and numerous witnesses will at any time confirm it - that all of the record flights from beginning to end were pure helicopter flights and, for the purpose of putting to nought any such doubts as those of Asboth, that each landing was effected vertically as a pure helicopter. The pilot was expressly requested to do that by the sport witnesses of the F.A.I., whose unimpeachability Asboth will probably not question. It is true, as has been said, that aside from the record flights, the aircraft has made many repeated landings with engine stopped. Before the flight of this particular machine, no helicopter has been able to effect a smooth landing with power off, including Asboth's own helicopter.

The attainment of an altitude of 2,439 meters in helicopter flight is based on knowledge which, judging by Asboth's computations, was not available to him. I agree with Asboth that no technical wonders have been accomplished, but the results have been obtained after an unbroken five-year period of continuous work on the helicopter problem. I cannot help it that in his article, Asboth shows repeatedly that he is unacquainted with my work. Furthermore, the construction of the helicopters, the results of years of computations, wind-tunnel and full-scale tests originate with me alone, however much Asboth seems to doubt it and claims that good helicopters aside from his own are quite unknown. He appears to forget that by patience, hard work, and knowledge any technical result may be achieved that is not contrary to the natural laws.

In June the German Government took over the first helicopter and in October the second. The latter helicopter was flown in October 1937 by Hanna Reitsch from Bremen to Berlin wherein she further improved the world record between Stendal and Tempelhof to 108.947 km/h (67.67 m.p.h.). No one, myself included, had considered such performance from a first design with small excess power to be possible. It is just this fact, however, which so strikingly brings out the great possibilities which are offered by helicopter flights for the future.

Translation by S. Reiss,
National Advisory Committee
for Aeronautics.

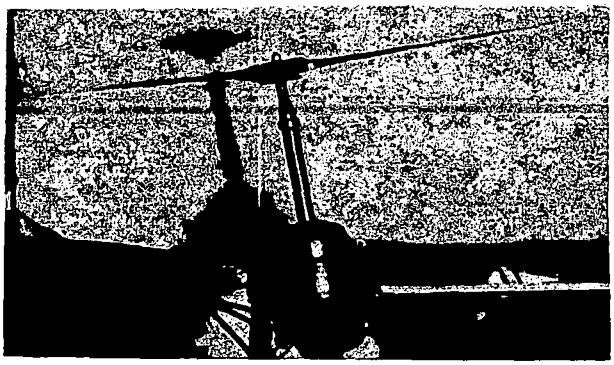

Figure 1.- Model of three-blade propeller driven by a 3 hp. electric motor for tests in wind tunnel.

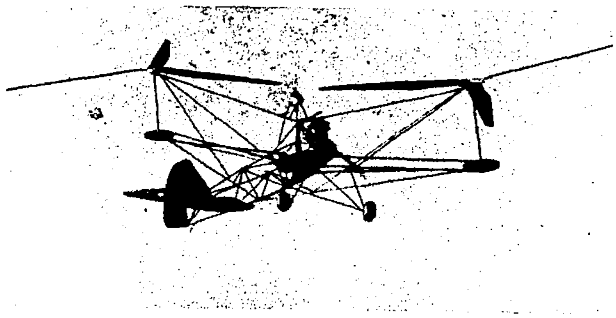

Figure 6.- A Focke free flying model helicopter driven by a 0.7 hp. gasoline engine. The model attained an altitude of 18 m.

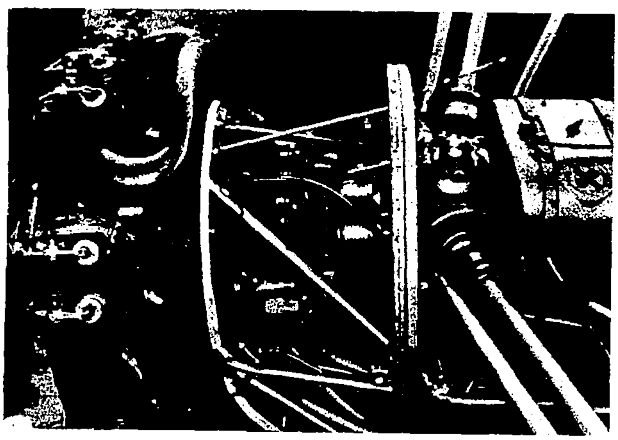

Figure 7.- Bevel gear drive with friction coupling.

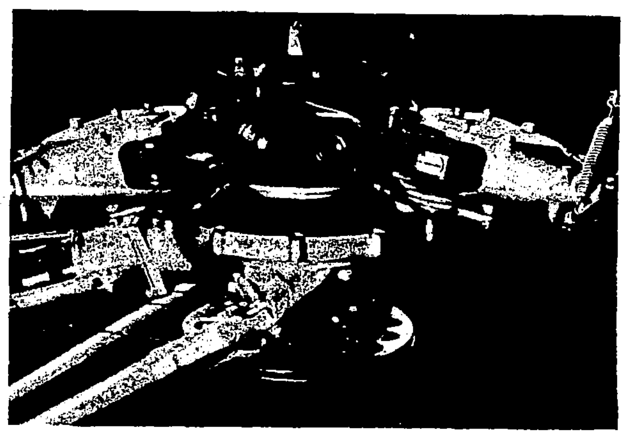

Figure 8.- A propeller hub with the control parts for the blade motion.

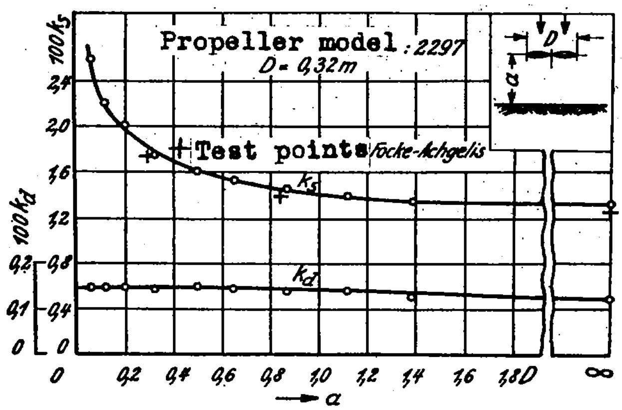

Figure 2.- Results of Flachsbart on the ground effect on a propeller.

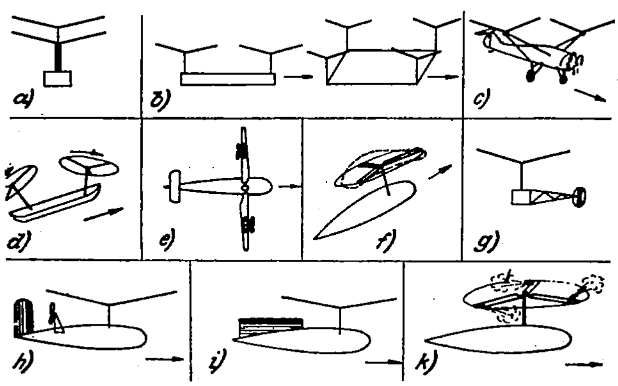

Figure 3.- Proposals for balancing the helicopter propeller moments.

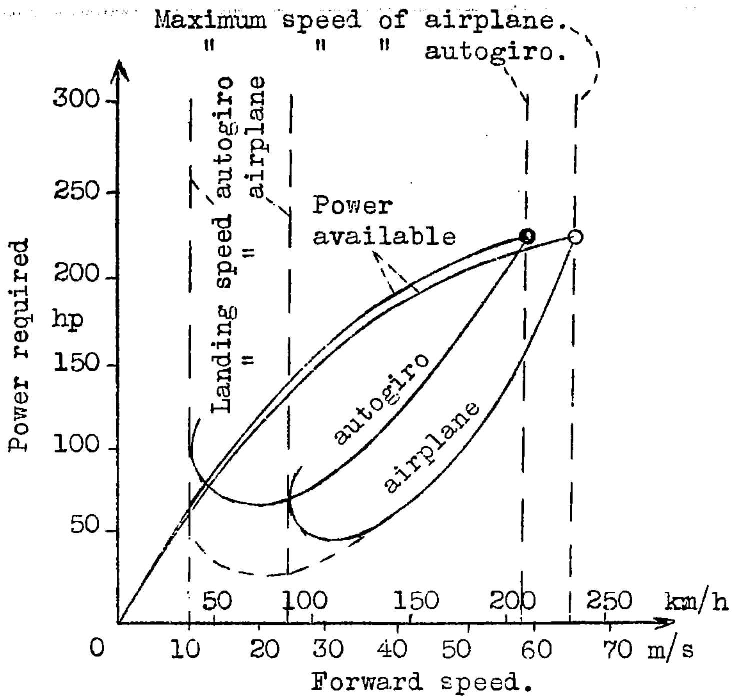

Figure 4.- Comparison of required and available power of conventional airplane and autogiro.

	Rate of climb m/s	Weight kg
F.W. 44 Stieglitz airplane.	3.5	870
Cierva C 30 autogiro.	1.5	815
F.W. 61 Helicopter as autogiro (windmill).	1.3	950
F.W. 61 Helicopter as helicopter.	3.6	950

Figure 5.- Comparison of airplane, autogiro and helicopter.

Figure 10.- Model aircraft being tested while still "captive" on ground.

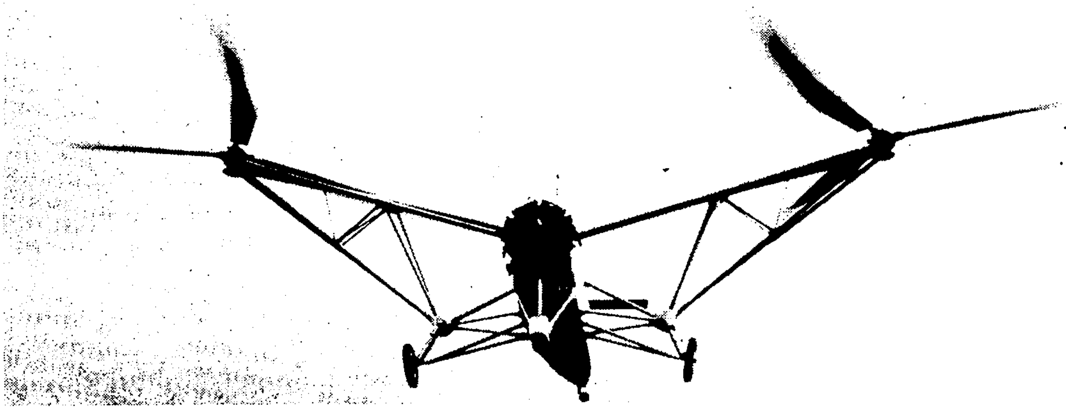

Figure 11.- The first free flight carried out by Rohlfs June 26, 1936.

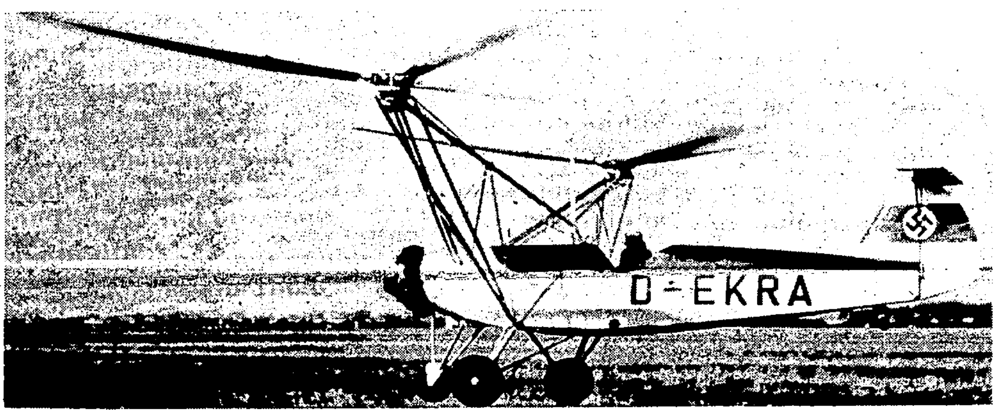

Figure 9.- View of the helicopter with the propeller used for cooling.